

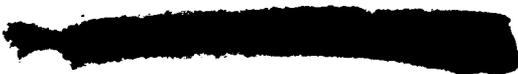
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**RIBLETS FOR AIRCRAFT  
SKIN-FRICTION REDUCTION**

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## ABSTRACT

Energy conservation and aerodynamic efficiency are the driving forces behind research into methods to reduce turbulent skin friction drag on aircraft fuselages. Fuselage skin friction reductions as small as 10 percent provide the potential for a 250 million dollar per year fuel savings for the commercial airline fleet. One passive drag reduction concept which is relatively simple to implement and retrofit is that of longitudinally grooved surfaces aligned with the stream velocity. These grooves (riblets) have heights and spacings on the order of the turbulent wall streak and burst dimensions. Present paper summarizes riblet performance (8 percent net drag reduction thus far), sensitivity to operational/application considerations such as yaw and Reynolds number variation, an alternative fabrication technique, results of extensive parametric experiments for geometrical optimization, and flight test applications.



## RIBLETS

Local skin friction reductions as large as 8-10 percent have been experimentally measured in the wind tunnels at NASA Langley Research Center. The research has reached a stage where flight applications are near term. The riblets are now available on a thin vinyl film with adhesive backing. This film could be applied to new as well as existing aircraft. Data indicate that the film could be applied to both fuselage and wing surfaces. The 8-percent local skin friction reduction would therefore translate into an 8-percent reduction in the turbulent viscous drag of the aircraft, or approximately 4 percent aircraft drag. An added advantage of the riblet drag reduction technique is that it is passive.

Bottom line - 8 percent aircraft viscous drag reduction  
for CTOL aircraft, retrofittable and passive

## WHAT ARE RIBLETS?

Riblets are streamwise surface striations that are aligned with the local free-stream velocity. The typical cross section of an optimum riblet is shown on the slide. The optimum and most practical riblet has sharp valleys and sharp peaks. The purpose of the riblets is to modify the near-wall structure of the turbulent boundary layer. The spanwise surface variation down in the cross section imposes a strong spanwise viscous force that creates a wall slip layer.

Riblet  $\equiv$  streamwise surface striation

Cross section  $\rightarrow$  

Purpose - Alter turbulence dynamics near the wall by imposing/utilizing strong spanwise viscous forces to create a wall slip layer

## **APPLICATION ISSUES RESOLVED**

The work at Langley Research Center has resolved many of the application issues. The present paper discusses test results on optimum riblet geometry, maximum drag reduction, riblets scaling for drag reduction at flight conditions, yaw sensitivity, and a practical application technique.

- Optimum geometry for maximum drag reduction
- How much drag reduction?
- Scaling (wind tunnel to flight)
- Yaw sensitivity
- Retrofittable application technique

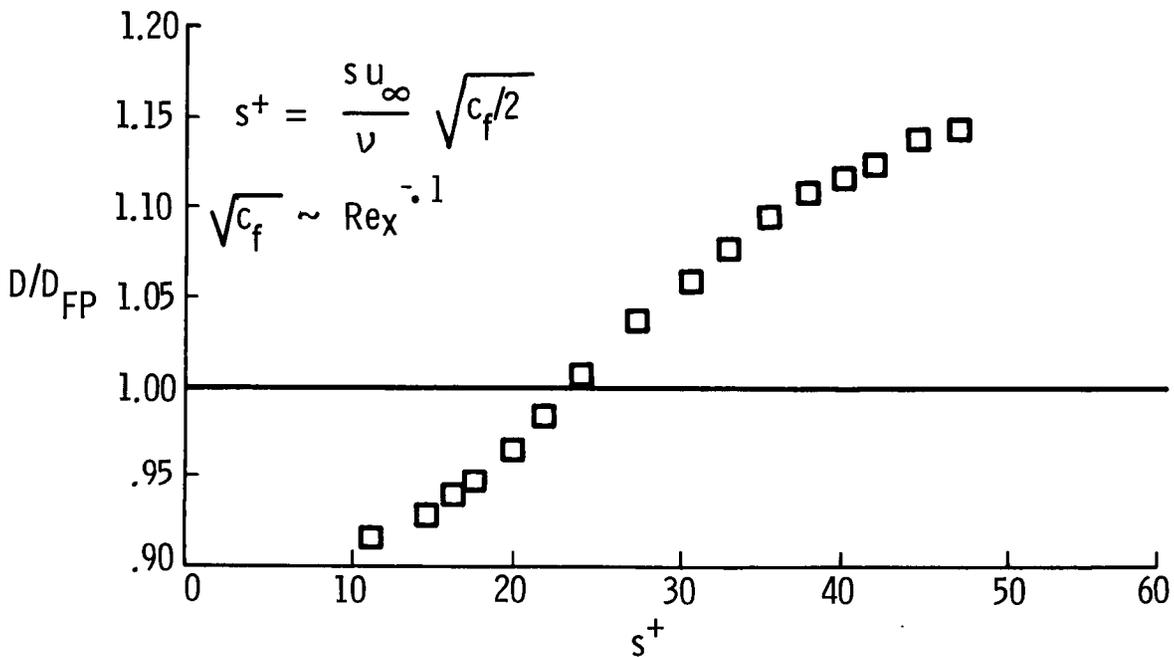
## RIBLET MODELS TESTED

Determination of optimum riblet geometry required parametric testing. This slide indicates the range of shapes studied. The test results show that the symmetric v-groove gave the maximum drag reduction performance. The peaks and the valleys of the grooves should be relatively sharp for maximum drag reduction.

<u>Model</u>	<u>Description</u>
	Symmetric V-groove
	Rectangular
	Spaced triangular
	Right angle rib
	Peak curvature
	Valley curvature
	Peak and valley curvature
	Notched peak
	Spaced V-groove
	Unsymmetric groove
	Oblique V-groove

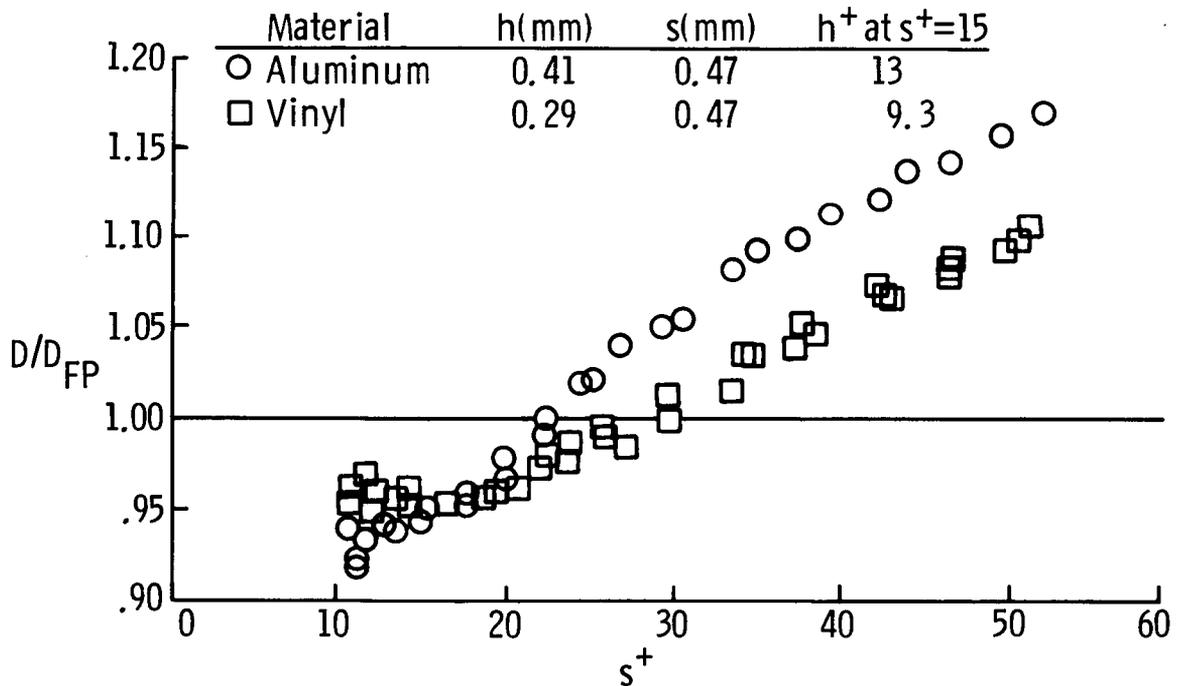
## OPTIMUM RIBLET

This slide presents net drag data for an optimum riblet surface that was tested in the low-speed wind tunnel at Langley. The drag data is referenced to the drag of a flat plate reference. The horizontal coordinate is the spacing of the grooves in wall coordinates,  $s^+$ . The parameter  $s^+$  is related to the free-stream velocity and skin friction as shown in the equation on the slide. The maximum drag reduction of 8 percent was found to be insensitive to upstream history and free-stream velocity as long as the physical dimensions of the riblet were sized to an  $h^+$  and  $s^+ = 15$  at the operating free-stream velocity of interest. The parameter  $h^+$  is the height of the groove in wall coordinates. This scaling of the drag reduction in wall coordinates allows the extrapolation of the low-speed wind tunnel results to a flight environment. The equations for  $s^+$  and  $\sqrt{C_f}$  shown on the slide indicate that the physical size of the riblet for drag reduction is only a weak function of  $Re_x$ , the Reynolds number based on distance along the aircraft fuselage ( $1/10$  power). Therefore, the riblet dimension could be fixed for a particular aircraft rather than varying drastically along the fuselage.



## VINYL FILM RIBLET

The previous slide indicated the riblet scaling parameters. The next step to achieving a flight-capable device was to find a practical fabrication technique. The method advocated by 3M Co. was to make the riblets on a vinyl film with an adhesive backing. This slide shows drag data obtained with a vinyl riblet compared to a riblet which had been machined on an aluminum surface. Due to the manufacturing process, the aspect ratio ( $h/s$ ) for the vinyl riblet was somewhat smaller than that for the aluminum riblet. The reduced aspect ratio of the vinyl riblet resulted in a smaller drag reduction than that obtained with the aluminum riblet. The data are significant in that drag reduction was obtained on a surface suitable for aircraft application.



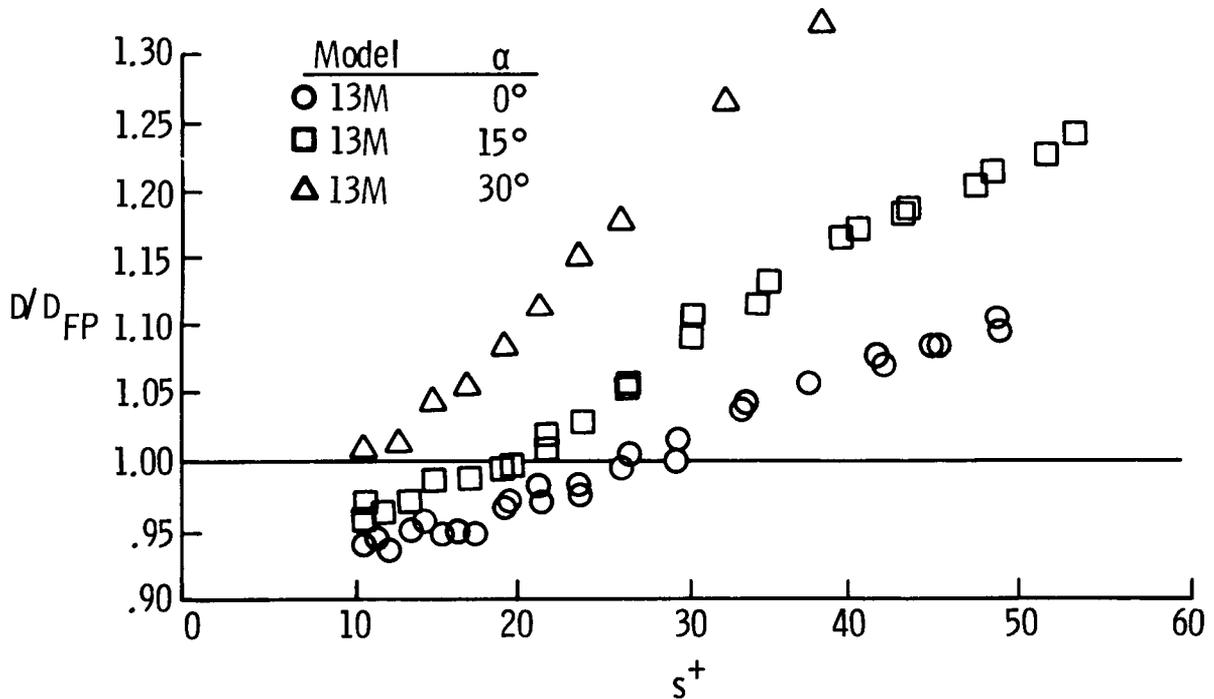
FLIGHT TEST FILM

The scaling parameters have been used to determine the physical dimensions of a riblet film suitable for drag reduction at flight conditions. The slide shows a micro-photograph of a riblet film to be flight tested in July 1985. The physical height and spacing of the riblet is 0.0013 inch. Despite the overall physical size the film still has sharp peaks and valleys.



## EFFECT OF YAW

Another aspect of a flight application is the yaw sensitivity of the riblets. All data shown previously have been for zero angle of yaw. This slide shows the vinyl film at 0°, 15°, and 30° yaw. There is little change in the maximum drag reduction at 15°; however, all drag reduction is lost at 30° yaw. In a riblet application it would be important to keep the grooves aligned with the flow within 15°. For cruise the near surface streamlines are usually in this less than 15° range for CTOL aircraft.



## SUMMARY OF RIBLET PERFORMANCE

The riblet drag reduction appears to result from the spanwise velocity gradient  $\partial u/\partial z$ . There is a thickening of the viscous near wall region that moves the turbulent fluctuations further from the wall. This whole process reduces the turbulent production magnitude. The basic turbulence interaction process is unaltered. A maximum drag reduction of 8 percent is obtained with a sharp peak v-groove having a space and height  $O(15^+)$ . The drag reduction is present up to  $15^\circ$  angles of yaw; however, by  $30^\circ$  yaw, the drag reduction is lost. Vinyl riblets provide a simple method for application to new aircraft as well as aircraft presently flying.

- Spanwise geometry causes a  $\partial U/\partial z$ 
  - Thickens viscous region near the wall
  - Moves turbulent fluctuations further from the wall and reduces turbulence production magnitude
  - Turbulence interaction/production processes unaltered
  - Basically, provides a "slip layer" at surface
- Maximum drag reduction for riblets 8 percent
  - Optimum geometry is V-groove with "sharp" tips
  - Optimum size is  $O(15^+)$
  - Insensitive to yaw angles up to  $15^\circ$
  - Vinyl riblets make aircraft applications simple and retrofittable

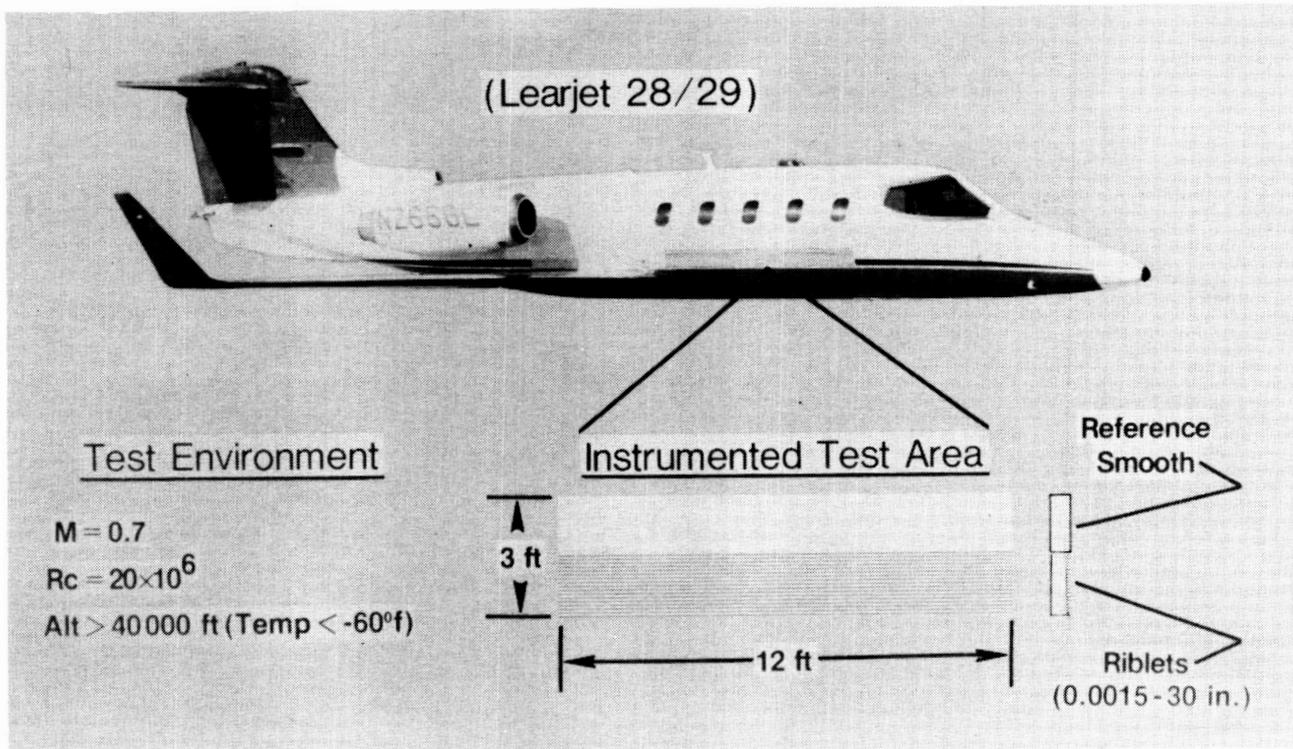
## REQUIRED AND ONGOING RESEARCH

Ongoing research at Langley is presently focusing on increasing the riblet drag reduction performance by increasing the aspect ratio ( $h/s$ ) of the riblet geometry. Present data indicate that the drag reduction increased with aspect ratio with a maximum value of one tested thus far. Further research will attempt to increase the aspect ratio above one. Now that the scaling of the riblet drag reduction has been firmly established, the wind tunnel results can be used to extrapolate to flight conditions. Two sets of flight tests are planned in the near future: a subsonic test at  $M \approx .7$  on the fuselage of a Learjet; and a  $M \approx 2.0$  test on a flight test fixture mounted on the underside of the fuselage of an F-104G aircraft at Dryden Flight Research Facility. Details of these upcoming flight tests will be discussed on the next two slides. Tests are also planned in the 7' x 10' tunnel in 1986. These tunnel tests will be conducted at high  $U_\infty$ ,  $Q_\infty$ , and  $Re_x$  ( $100 \times 10^6$ ). Also to get the riblet film ready for fleet application, the following areas will have to be examined: durability, porosity, ultraviolet sensitivity, and clogging. The need for a porous film will be discussed further in a later slide.

- Improved performance (increased H/S)
- Flight tests
  - Learjet fuselage at  $M = .7$  (July 1985)
  - Dryden,  $M = 2$  (May - June 1985)
- High  $U_\infty$ ,  $Q_\infty$ ,  $Re_x$  ( $100 \times 10^6$ ) tests in 7' x 10' tunnel (1986)
- Long duration flight readiness
  - Durability
  - Porosity
  - Ultraviolet sensitivity
  - Clogging

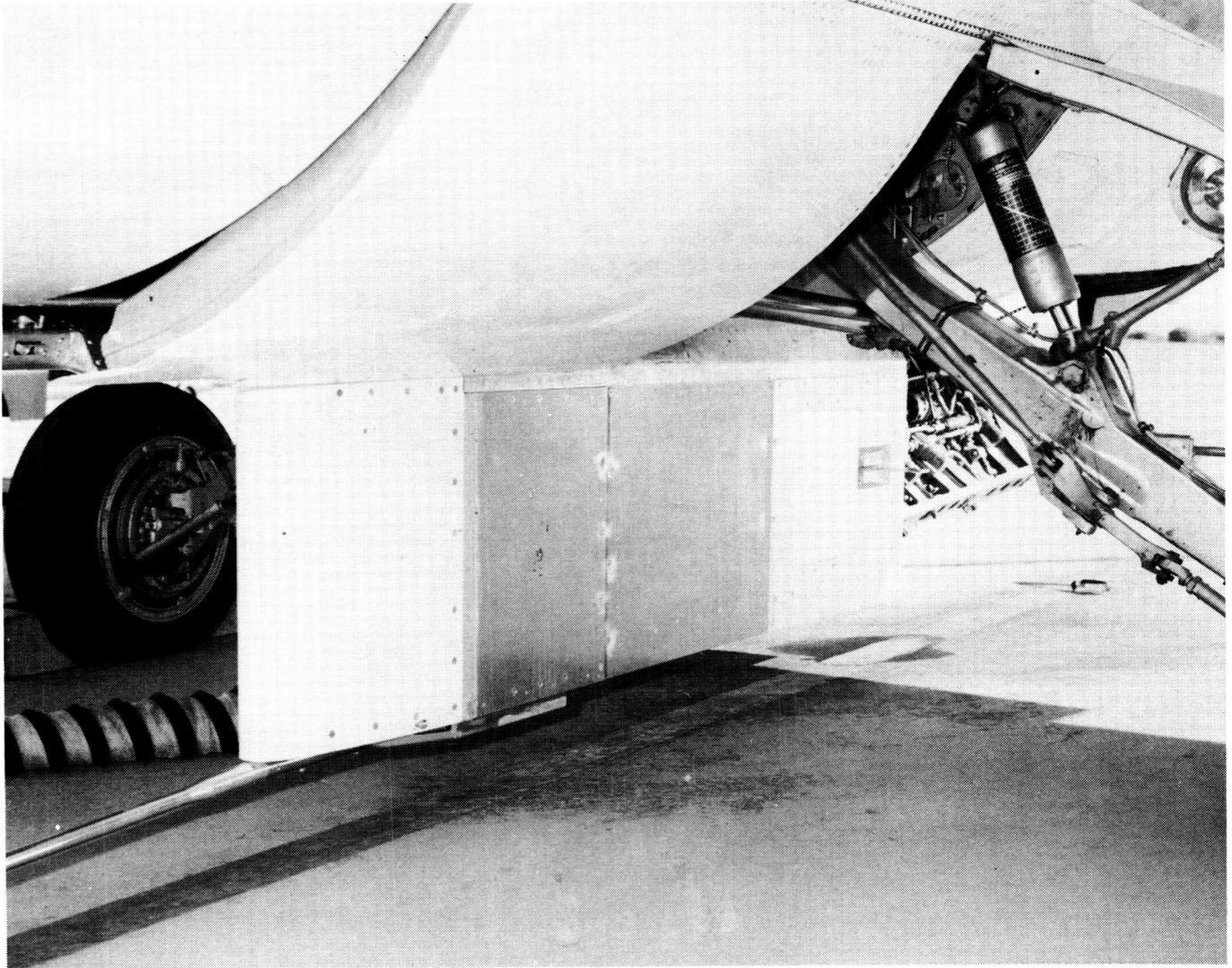
### TURBULENT DRAG REDUCTION FLIGHT RESEARCH

This slide shows a photograph of a Learjet Model 28/29 aircraft to be used for riblet flight tests in July 1985. The riblet film will be tested at Mach numbers up to 0.8 and Reynolds number per foot up to  $3.0 \times 10^6$ . Drag reduction performance will be measured with a drag balance and a boundary layer rake. Two riblet films will be tested: one with  $h = s = 0.003$ " and the other  $h = s = 0.0013$ ".



## FLIGHT TEST FIXTURE ON F-104G

This slide shows the flight test fixture mounted on the underside of the fuselage of an F-104G aircraft at Dryden Flight Research Facility. The test fixture can provide data for Mach numbers 0.4 to 2.0. A drag balance and a boundary layer rake are mounted on each side of the fixture. This test facility will provide data showing the supersonic drag reduction performance of the riblets. The tests are presently scheduled for May-June 1985.



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## NET EFFECT OF RIBLET APPLICATION

This slide summarizes the net effect of a riblet application. The riblet film has application to civilian as well as military aircraft. The riblet has the potential to reduce turbulent skin friction on the aircraft fuselage by 8 percent. This skin friction reduction on the fuselage and wing is associated with a displacement thickness reduction ( $\delta^*$ ) that results in a 6 percent reduction of the afterbody form drag. The riblet film itself, if made porous, could reduce the 5 percent of fuselage drag which is due to leakage from the pressurized cabins and the roughness drag of the aircraft by 3 percent. The summation of the riblet drag reduction benefits is a possible 16 percent reduction in fuselage drag or a 4 percent reduction in the net drag of the aircraft. In addition the riblet film would provide corrosion resistance and could be used as a substitute for paint. Many of the markings and decorations on aircraft flying now are made out of a vinyl film. Wing application benefits would be additive to these.

-CTOL

● Civilian

-SST

Percent drag reduction for fuselage



{ 8% direct CF reduction  
6% reduction of afterbody  
form drag



5% reduction due to modification  
of leakage from pressurized cabins



3% roughness drag reduction

Total fuselage drag reduction = 16%

Total aircraft drag reduction = 4%

● Additional benefits

- Corrosion resistance (cost reduction)
- Substitute for paint (colors molded into film) (cost/wt. reduction)

-Tanker

● Military-Transport (C130, C141, C5)

-Patrol (P3)

Source

Control of wall turbulence,  
 $\delta^*$  reduction upstream of  
afterbody region

Converting jet leakage into  
porous injection

Smoothing due to surface film